Calhoun
Institutional Archive of the Naval Postgraduate School

Calhoun: The NPS Institutional Archive

DSpace Repository

Theses and Dissertations 1. Thesis and Dissertation Collection, all items

1959

Investigation of moving striations in an inert high purity gas discharge

Fiedler, Peter B.; Johnson, William J.

Monterey, California: U.S. Naval Postgraduate School

http://hdl.handle.net/10945/14337

Downloaded from NPS Archive: Calhoun

DUDLEY KNOX LIBRARY

Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

http://www.nps.edu/library

NPS ARCHIVE
1959
FIEDLER, P.

INVESTIGATION OF MOVING STRIATIONS IN AN INERT HIGH PURITY GAS DISCHARGE

PETER B. FIEDLER
AND
WILLIAM J. JOHNSON

LIBRARY
U.S. NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA

INVESTIGATION OF MOVING STRIATIONS

IN AN

INERT HIGH PURITY GAS DISCHARGE

* * * * * *

Peter B. Fiedler

and

William J. Johnson

INVESTIGATION OF MOVING STRIATIONS
IN AN
INERT HIGH PURITY GAS DISCHARGE

8854

by

Peter B. Fiedler

Lieutenant, United States Navy

and

William J. Johnson

Lieutenant, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

IN

PHYSICS

United States Naval Postgraduate School
Monterey, California

1 9 5 9

NPS ARCHIVE
1959
FIELDER, P.

Thesis
F39

INVESTIGATION OF MOVING STRIATIONS

IN AN

INERT HIGH PURITY GAS DISCHARGE

by

Peter B. Fiedler

and

William J. Johnson

This work is accepted as fulfilling

the thesis requirements for the degree of

MASTER OF SCIENCE

IN

PHYSICS

from the

United States Naval Postgraduate School

ABSTRACT

The belief that high purity gas is of great importance in the study of moving striations has led to the design and construction of a system capable of achieving this end. An ultrahigh vacuum system in conjunction with a cataphoretic gas purification system are described and their capabilities and limitations are discussed. Pressures as low as 2 x 10^{-9} mm Hg have been reached and maintained.

A discharge tube with movable electrodes along with measuring equipment consisting of a rotating mirror, movable probe, dual beam oscilloscope, photo-cell, and an electronic counter are described and illustrated.

The time available was not sufficient to obtain adequate results to justify drawing valid conculsions, but several phenomena are considered worthy of note, i.e.:

(a) Modes seem to be dependent on history of discharge.

(b) Three distinct positive column configurations were observed.

(c) Stability was gradually obtained and subsequently lost.

(d) External circuitry had a pronounced effect on the discharge.

The writers wish to take this opportunity to express their sincere appreciation to Assistant Professor A. W. M. Cooper for his tireless guidance and efforts and to Professor N. L. Oleson and the other members of the Physics Department of the U. S. Naval Postgraduate School who gave their assistance in this investigation.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1. Introduction

It has become evident that oscillations and moving striations, regions of luminosity which vary in light intensity with time and position, are not uncommon to a glow-discharge, but are on the other hand to be expected whenever a positive column exists. There are cases when this is not true but these are now considered to be the exceptions rather than the rule. Up to the present time there has not been a suitable mechanism presented that describes the entire phenomenon probably owing to the difficulty of obtaining precise measurements. Much of the experimental work has been done by use of rotating mirrors, probes, photo-cells in conjunction with a cathode ray oscilloscope, and more recently by using pulsing techniques (1).

The work described in this thesis is mainly experimental and deals with some of the areas not covered throughly by other investigators, i.e.: the purity of the gas used, use of an ultra high vacuum system, probe effects on the plasma, and the effects on variable spacing of the electrodes upon the frequency.

The purity of the gas used in the past, in most cases, was either considered sufficient or of little importance. In this thesis the purity is one of the major considerations and considerable time and effort has been directed toward this end and consequently a cataphoretic purification system was built into the vacuum system. It has been suggested by several investigators (15) that the mechanisms for propagation of striations is influenced by the presence of trace concentrations of a foreign gas, therefore the purification system was coupled to an ultra-high vacuum system in order to investigate this possibility.

The effects of a probe upon the plasma may be serious (21). Surrounding the probe is a space charge sheath in which the charge distribution is not the same as that of the undistrubed plasma (21). Positive striations, striations which move towards the cathode, have been observed to vary in velocity upon approaching a probe (2).

The potential difference between the reference electrode and the probe may not be the true difference unless the metals used in both are the same and have had similar histories with regard to heating and bombardment. It is fairly certain (21) that there will be a contact potential difference in work functions. Oatly and Weissler (21) have shown that work functions change during the time under bombardment by H+ ions by as much as 1.6 to 2.0 v. These effects definitely complicate the correct interpretation of measurements. In the current investigation, a study will be made through use of a rotating mirror and a photo-cell in conjunction with a dual beam oscilloscope on the effects of the probe on the plasma.

Using movable electrodes, the reported change in frequency accompanying a change in interelectrode distance (29) will also be studied since the details of the manner in which this was performed were not given.

2. Review of previous experimental work

Work in this field began as long ago as 1843 when glow-discharges were discovered by Abria. Since then a great many investigators have studied this phenomenon. In 1921 Aston and Kikuchi (16) studied moving striations by means of a rotating mirror and found that the positive striation velocity varied in-

versely as the square root to the gas pressure and increased with decreasing tube radius. The amount of impurity in the gas influenced the velocity and the velocity did not remain constant over the entire length of the tube. Later they observed that there existed more than one type of moving striation. Three types were observed all of which had different velocities and all of which moved towards the cathode. Two or all three types were found to exist at the same time in different parts of the positive column. It is noted that although Aston and Kikuchi observed that impurities had an effect on the velocity they did not state what this effect was or how it varied with varying concentrations of impurities (or different impurities). In the current investigation a controlled amount of impurity was planned on being used, but lack of time did not permit this to be accomplished. Observations would have been made of the discharge to see what effects would have been produced.

In the period between 1925 and 1930 striations were studied by Whiddington (15), again using a rotating mirror. In his earlier studies he obtained results that agreed with those of Aston and Kikuchi, except he noted that the discharge current had a periodic fluctuation and the speed of the striation did not vary with the voltage applied across the tube and that the spacing between striations remained constant. It was also observed that there was no Doppler shift seen from the sources of light indicating that these sources were not moving with the velocity of the striations. Later Whiddington found that striations in an impure gas were non-uniform sometimes evidenced by two different sets of striations with different velocities and

frequencies in separate parts of the tube at the same moment. As mentioned earlier, this observation was also made by Aston and Kikuchi although they did not attribute this phenomenon to impurities which is another eason that a study of impurity effects should be undertaken.

What may result in being a very significant discovery was made by Takamine, Suga, and Yanagihara (17) in 1933 who showed that there was a relationship between moving striations and anode spots. Farris (26) suggests that there may be a correlation between these spots and the negative striations (those which move towards the anode) observed by Donahue and Dieke (24) in that the ratio of anode spot oscillations to positive striations leaving the anode as reported by Takamine et al. is similar to that of negative striations to positive as reported by Donahue and Dieke. There appears to be fertile ground here for further investigation.

Up to the present time the only paper describing the spatial configuration of ion density, electron temperature, and space potentials in the positive column of a glow-discharge in which moving striations are present was written by Pupp (12) in 1935. The measurements obtained by means of a double probe system show that the electron and positive ion densities are everywhere almost identical and that ion density varies by a factor of about ten from one part of the striation to the other. The results are open to question, based upon the inherent errors in probe measurements discussed earlier, but remain the best available to the present time.

An exhaustive survey was made by Donahue and Dieke in 1948 and 1949 at Johns Hopkins University. They were the first to report the presence of what they called negative striations. Using a photo-cell and an oscilloscope along with a multitude of tubes of various diameters, and using hydrogen, mercury, and the rare gases at various pressures they reported that when a positive and a negative striation meet they both come to rest for a finite period of time and then separate and continue on in their previous directions. This phenomenon always occurs at the same place in the discharge. Also worthy of mention is the fact that the striations cease when the anode enters the Faraday dark space.

An interesting result was obtained by Zaitsev and Mitsuk(1) who, by pulsing a discharge tube with variable length voltage pulses, reported that striations appear first at the cathode end of the positive column, and that stratification gradually extends toward the anode at a rate which reaches a few thousand meters per second.

3. Review of previous theoretical work

Time does not permit discussion of all the proposed theories of this phenomenon and therefore only the more salient theories will be treated. An early theory proposed by Widdington assumes a plasma to exist initially throughout the tube, in which the electrons near the anode are attracted to it by the electrostatic field thereby leaving a positive space charge behind which is repelled by the anode this allows the plasma to again form and the process is repeated. After the next positive space charge is formed it also moves away from the anode repel-

ling its predecessor in the same manner as it is being repelled by the anode. This suggests that the striation velocity should be independent of the tube voltage except near the anode which has been shown to be the case. The absence of a Doppler shift does not substantiate this theory although evidence for the absence is not conclusive.[1] Another point which invalidates this theory is that the drift velocities of the positive ions would have to be entirely too large considering the electric fields present in the positive column.

The next theory considered is that of Donahue and Dieke (24) who postulate that the movement of striations in the positive column depends on the occurrence of cumulative ionization. The mechanism is complete enough that it will be treated in some detail, not just because it is complete, but because it depends upon some important points that are under investigation in this thesis, i.e.: metastable state effects. Before discussing cumulative ionization the mechanism proposed by Donahue and Dieke for movement of electrons from the cathode glow into the positive column after losing energy by excitation will be considered. Electrons would be expected to accumulate in the cathode glow since there is evidence that a potential minimum exists near the Faraday dark space. This would serve as a trap for electrons and as this negative space charge builds up it would spread to the cathode thereby decreasing the cathode fall and would probably extinguish the discharge unless some means exists for removing the excess charge from the negative glow. It

[1] It is hoped that the presence or absence will be shown using a high dispersion grating spectrograph soon to be acquired by the U. S. Naval Postgraduate School.

appears that the positive striations may be the means whereby the removal of electrons is accomplished. When a positive striation comes near enough to the trapped electrons the potential minimum is raised enough to allow the electrons to escape - this burst of electrons is called the negative striation. Apparently this leaves behind a positive space charge which travels to the cathode, raising the cathode fall and causing greater emission of electrons (a negative striation). The two meet at the cathode side of the negative glow neutralizing each other and the electron entrapment begins again.

Positive striations themselves form a trap in which a concentration of electrons builds up. These electrons are subsequently removed by the succeeding positive striation in the same manner that the electrons were released from negative glow. Eventually one of the negative striations reaches the high potential field of the anode acquiring sufficient velocity to create a cloud of ions which in turn shield the anode causing the current to drop and the space charge to build up until it moves away from the anode under the action of repulsive forces and by cummulative ionization as described in the following paragraph. This completes the cycle.

Cumulative ionization is considered by Donahue and Dieke to be the process whereby atoms of the gas are ionized in successive stages passing through a metastable state assuming that the only effective process of ionization is through collisions between electrons and metastable atoms. Assume a positive space charge peak at a point x, (Ref. Figure 1) a metastable peak at $x - \Delta x$, and a rate of metastable production peak at x_1.

This is the situation that would exist if the electrons had

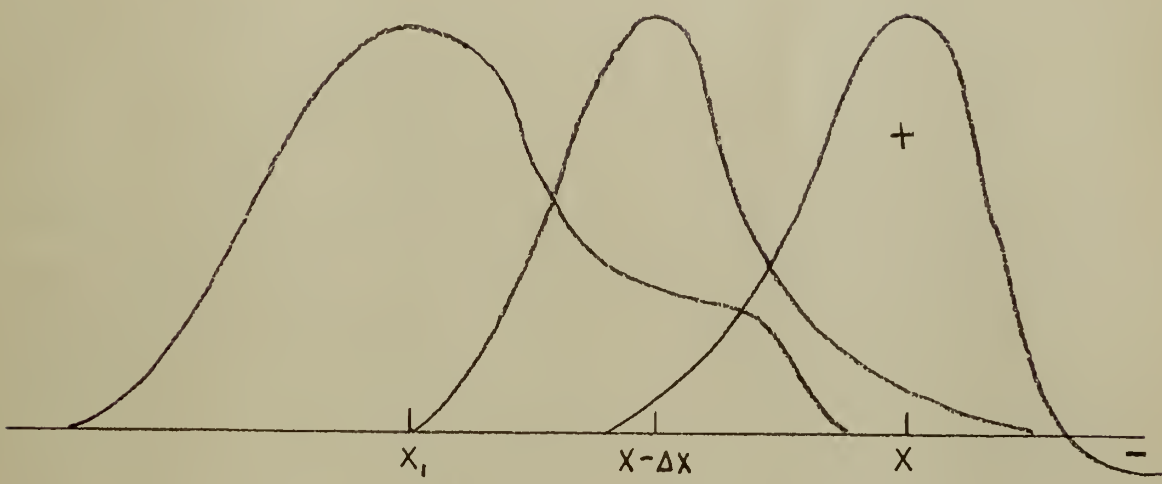


Figure 1

risen in energy so that the peak in their energy distribution were just above the levels of the metastable states when they arrive at x_1. The electrons after leaving x_1, having undergone a sharp drop in energy due to inelastic collisions there, would gain energy in the electric field due to the positive space charge and when they reached $x - \Delta x$ they would produce highly excited atoms as well as ions since this is the region where the concentration of metastables is high. At x very little ionization takes place due to the low concentration of metastable atoms and the low energy of the electrons. Ion concentration falls at x due to diffusion to the walls and recombination, while at x_1 the metastable concentration rises as does the ion concentration at $x - \Delta x$ - the latter at the expense of the metastable atoms. Effectively what has happened according to Donahue and Dieke is that each region has moved

(shifted) toward the cathode and the process is continuous. Pupp's results show that all the assumptions made here are not valid (12). In the current investigation the existence of the metastable atoms is to be studied by introducing into the system a suitable foreign gas that has a resonance level of about the same energy as that of the metastable atom energy level of the gas being used and collisions between the two should, in most cases, result in the metastable atom going to the ground state while the foreign gas atom either becomes excited or is ionized. If the mechanism of Donahue and Dieke is correct then removal of the metastable atoms should result in the loss of moving striations.

Watanabe and Oleson (7) proposed to explain traveling density waves, as they called them, in the positive column by coupled diffusion equations for positive and negative ions. This coupling is justified on the basis that the electrostatic field generated by positive ions reacts on negative charges and vice versa, and that both positive and negative ions are formed by collisions of electrons with neutral molecules. The assumption was made that the solution to their equation was a combination of a steady state uniform solution with a small nonsteady, nonuniform disturbance. The assumption that the latter was small was made in order to linearize the equations. Several investigators (25) have pointed out that moving striations appear to be large amplitude disturbances and consequently their properties cannot adequately be represent by a treatment which omits the nonlinearities. Walsh, in fact, describes the characteristics of the striations solely by the nonlinear

terms in the continuity equations and the variation in electron energy with time. Chapnik in his development is also forced to solve a nonlinear equation and does so by treating it as an oscillation equation of a system with a nonlinear restoring force.

The theory developed by Schottsky (21), and Tonks and Langmuir (14) of the homogeneous positive column was extended by Druyvesteyn (8) to include moving striations by making the assumptions that the electrons always possess a Maxwellian velocity distribution and that the electron temperature is constant in a cross section of the column[2].

4. Discharge tube

Analysis of previous work in this field indicates that it is desirable to include in one tube the following options:

(a) A positionable Langmuir probe which may be introduced radially across the discharge providing radial distribution information.

(b) Movable electrodes to position the discharge axially with respect to the probe and also permitting variable anode-cathode spacing.

(c) A non-sealed tube permitting various pressures and gases to be used.

(d) Movable glass shields around the electrodes to eliminate sputtering to the discharge tube wall.

The tube constructed included all of the above features (Ref. Figures 2 and 3). The electrodes, glass shields, and probe can each be individually positioned by a small external magnetic

[2]Boyd and Twiddy (11) carried out a Druyvesteyn analysis electronically and found that the distribution is rarely Maxwellian and may even by anisotropic.

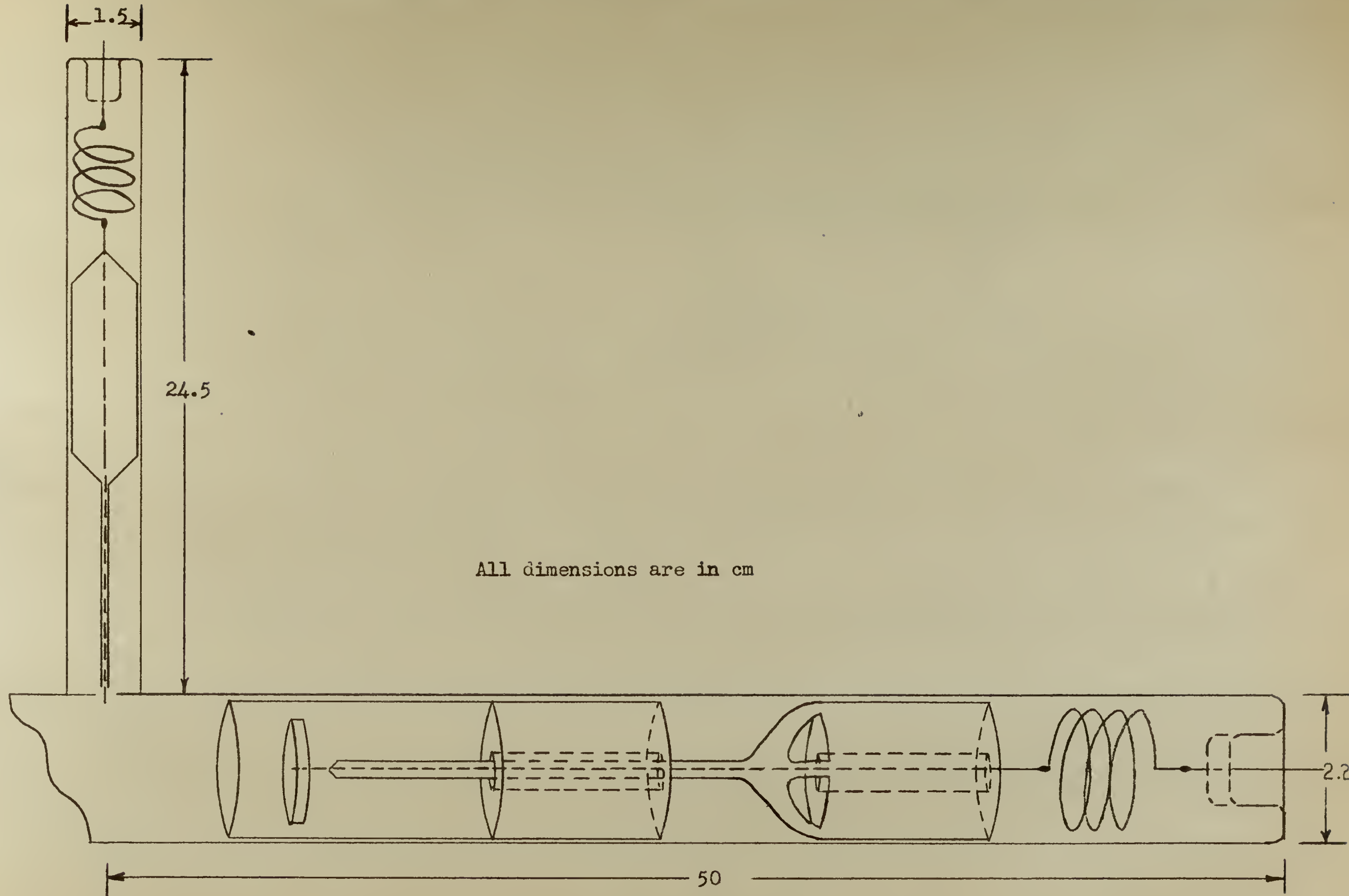


Fig. 2 Details of the Discharge Tube

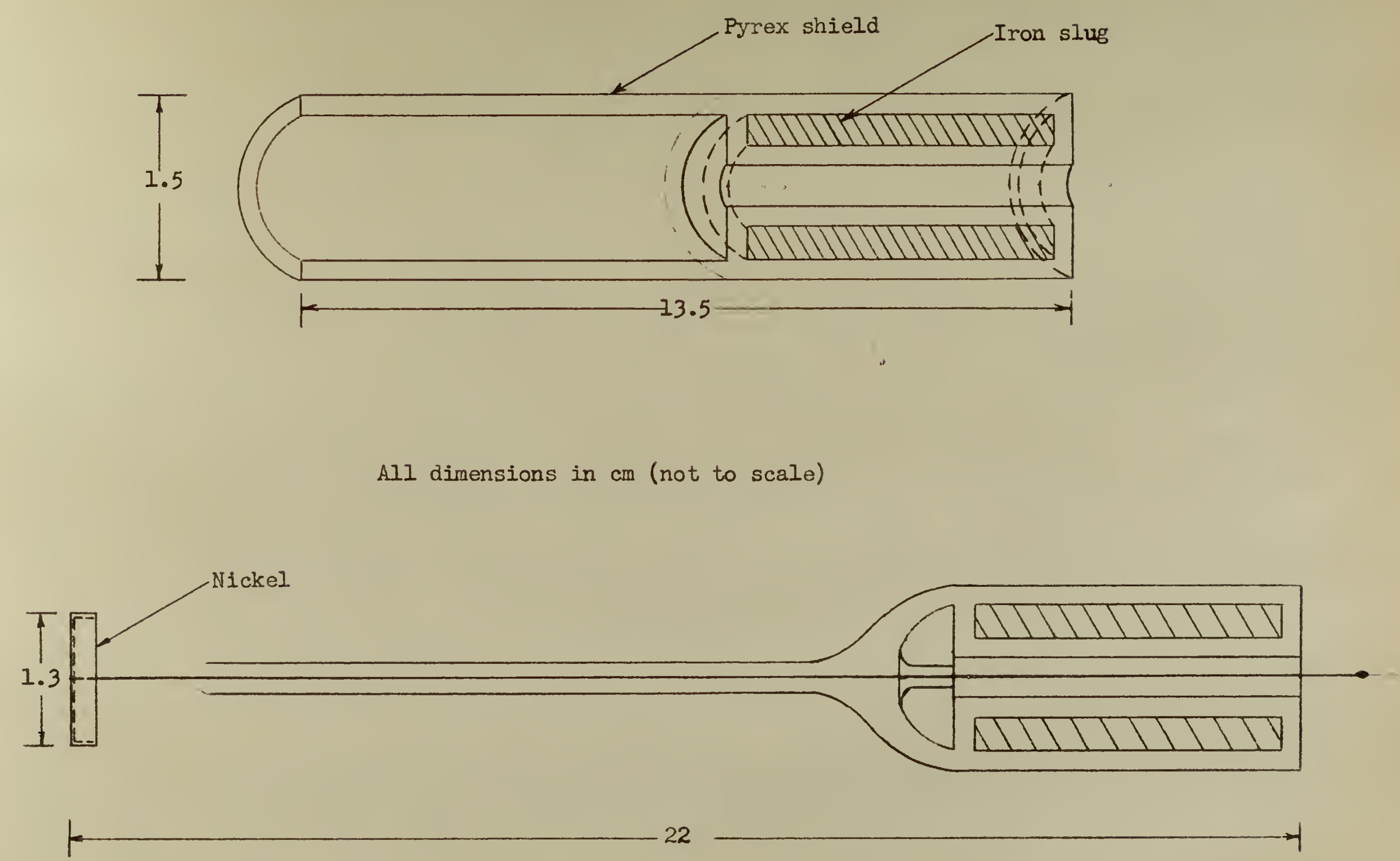


Fig. 3 - Details of moveable shield and electrode

field. The probe is a 3 mil tungsten wire, enclosed in a glass sheath, with 2mm of wire exposed. Exhausting is effected through the probe side arm via the probe entrance hole. The entrance hole was kept as small as possible to limit the discontinuity in the discharge wall to a minimum.

5. Vacuum system

The initial system was modified several times in the light of experience until a satisfactory system was attained. The design of the system is basically of the Alpert type built on a 123x71x85cm two level table. Large diameter glass tubing was used wherever possible in order to keep the pumping speed sufficiently high. A manifold was constructed into which all the components of the system, with the exception of the discharge tube itself, were connected as shown in Figure 4. Alpert valves were used through the main system although they proved to be less reliable than was expected. Their leak rate was so high that one valve alone could not prevent gas from the argon flask entering the high vacuum side until the latter rose to a pressure of about 4×10^{-4}mm Hg. Consequently we were forced to put two of these valves in series with the argon flask in order to reduce the leak rate to an acceptable level[3]. This seriously hinders obtaining accurately known gas mixtures so long as a large pressure differential exists across the valve. With small pressure differentials the valves are entirely satisfactory.

Two ion gauges were installed, one on the manifold and one

[3]Out of nine valves used none was able to maintain a sufficiently small leak with atmospheric pressure on one side and a high vacuum on the other.

below the table top which can be used while the baking out oven is in place. Initially a Consolidated Electrodynamics VG-1A ion gauge was used below, but it proved to be of insufficient ruggedness and was replaced by a Veeco RG-75P ion gauge identical to that on the manifold.

Several attempts were made to construct a non-contaminating instrument for measuring pressure in the 1mm to 20mm Hg range. A Bourdon gauge was tried first, but was too insensitive due to the "stiffness" of the diaphragm. A similar gauge with a diaphragm of suitable stiffness would be entirely satisfactory. We next tried to balance two Pirani gauges in a bridge circuit, but this was also too insensitive to be on any use. In order to expedite matters an oil manometer was used which limited the ultimate vacuum attainable to approximately 5×10^{-9}mm Hg (18) due to the vapor pressure of the fluid in the manometer (Octoil S vacuum pump fluid). The manometer is isolated from the main system by an Alpert valve and a liquid-air cooled copper-foil trap.

The electrodes of the discharge and cataphoresis tubes were degassed by induction heating them to a dull red color with the system at a pressure of approximately 10^{-6}mm Hg until there was no significant rise in pressure and then by bombardment with positive ions from a high voltage a.c. discharge. The entire system on the table top was then baked in an oven at a temperature of 430° C for 12 hours. At the same time the lower system was maintained at approximately 350° C while the fluid in the manometer was degassed thoroughly by heating it with a gas-oxygen flame.

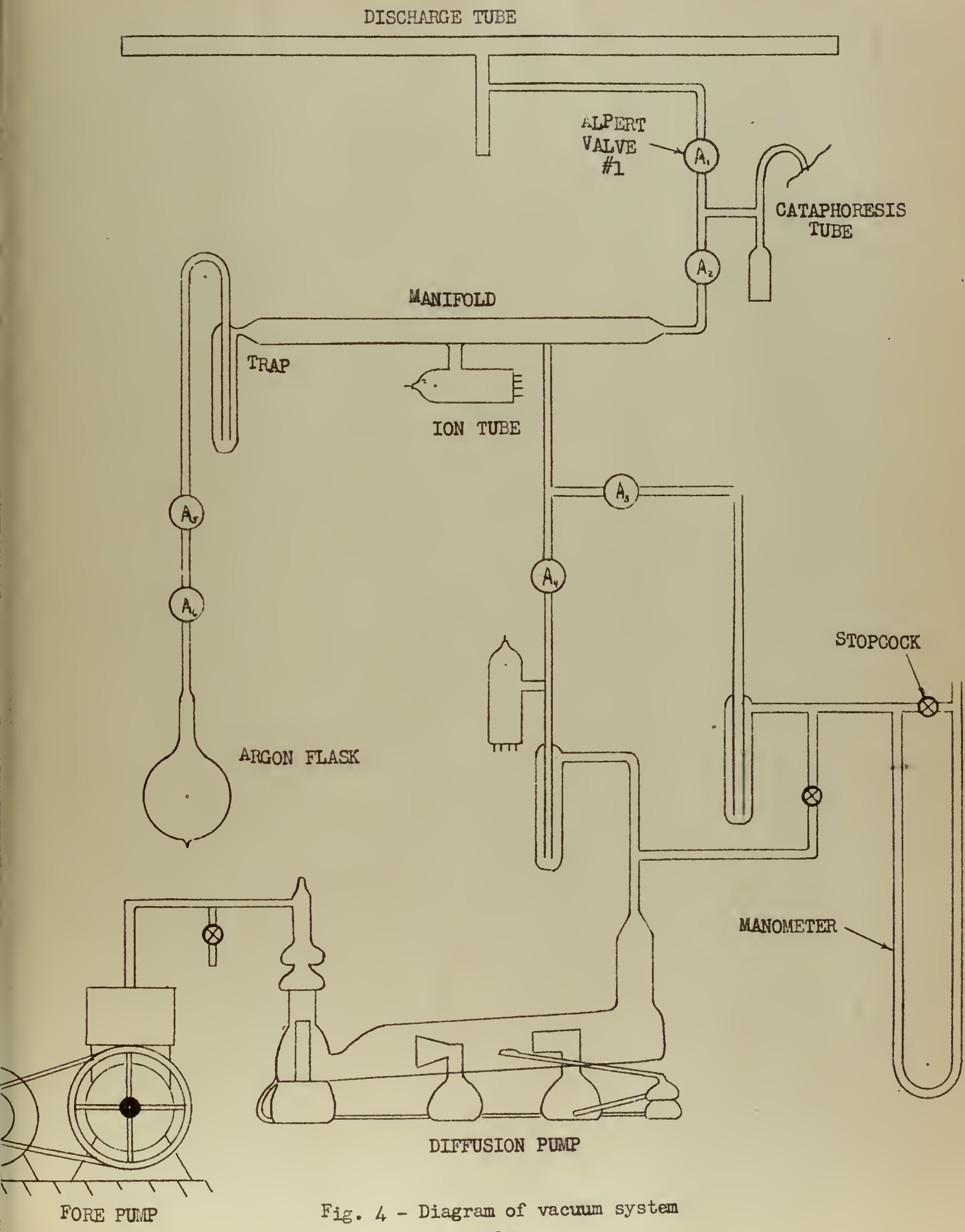


Fig. 4 - Diagram of vacuum system

The cataphoresis tube is isolated from the manifold by an Alpert valve with another valve in series separating the discharge tube from the cataphoresis tube. In this way the impurities collected at the cathode of the cataphoresis can be isolated from the discharge tube and then exhausted without affecting the discharge tube.

The filling system is simply an argon flask separated from the manifold by two valves in series, for the reason mentioned earlier, and a liquid-air cooled copper-foil trap. The Alpert valves provide an excellent means of controlling the rate of flow of the gas. During the initial evacuation and baking of the system the gas supply was isolated by a glass seal which was broken by means of a glass covered magnetic slug when the system had reached its ultimate vacuum.

After completing the degassing and baking processes the entire system was pumped down to 4.9×10^{-9}mm Hg and valve A_4 was closed. A_5 and A_6 were then closed and the seal to the argon flask broken. Argon was admitted to the main system through these same valves until the desired pressure was reached and both valves then closed. A_3, the manometer isolating valve, was then closed so that the system would not be exposed to the manometer any longer than necessary for a pressure measurement. At this point A_2 was closed, isolating the cataphoresis and discharge tubes from the rest of the system and then the cataphoresis tube discharge was struck. After operating for several hours in the above arrangement A_1 was closed and the discharge tube was ready for use.

To prevent contamination of the diffusion and fore pump

fluids in the event of leakage, a high pressure relay activated by the ionization gauge circuit was arranged to cut off the power supply to the pumps when the pressure rose to a preset value. To avoid damage to the pump fluid in the event of a temporary power failure (of which there were many) a time delay relay was incorporated in the power line to the diffusion pump. In this way on restarting an adequate fore vacuum is attained before the diffusion pump heaters are energized. When both the high pressure cut out and the time delay relay are used together the former overrides the latter.

6. Purification techniques

Previous work in the study of striations was limited to the 10^{-7}mm Hg for the initial pressure of the system. Since it is a major aim of this investigation to study the influence of trace impurities upon the striations, it was necessary to go several orders of magnitude lower before introducing gas into the system. Alpert (18) has shown that an ultimate limitation on the attainment of very low pressures in glass systems is due to the diffusion of atmospheric helium through the walls of the system which occurs around 10^{-11}mm Hg.

Cataphoresis, seen as early as 1893 and later observed in detail around 1930, is the phenomenon of selective grouping of minority ions in a gas discharge at the cathode end. Riesz of Johns Hopkins (6) advanced a qualitatively accurate theory based on a difference in ion mobilities of the major and minor gases present. Recent work in cataphoretic purification had shown this to be a feasible method for achieving extremely high purity gas (27).

Loeb (4) found that ionization of a minority gas, sufficiently complete to lead to rapid and effective concentration, is fairly well assured if the ionization potential of the vehicular gas lies above that of the minority gas species. Furthermore, Dieke (6) indicates that the efficiency of this method of purification with additional gettering provided by activated uranium maintained a pure helium discharge for two months.

The Johns Hopkins group noted that cataphoretic purification is effective for removing diatomic impurities, specifically: N_2, H_2, CO, and CH. It was further found that:

(a) The discharge tube should be long since the equilibrium concentration is expontial in length along the tube.

(b) The current should be as high as possible. This is to increase percentage ionization of the minor constituent.

(c) The axial field, or positive column voltage gradient, should be as large as possible. This implies as high a pressure and as small a tube diameter as is consistent with other requirements.

(d) The volume of quiescent gas at the cathode end of the tube should be large enough to accommodate the impurity concentration.

The tube used in this experiment is diagrammed in figure 5. The electrodes are made out of nickel and the discharge path is approximately 80 cm long. It is planned to run the discharge at 300 to 400 ma.

Other gettering techniques are given below:

(a) The addition of an activated uranium appears feasible (27).

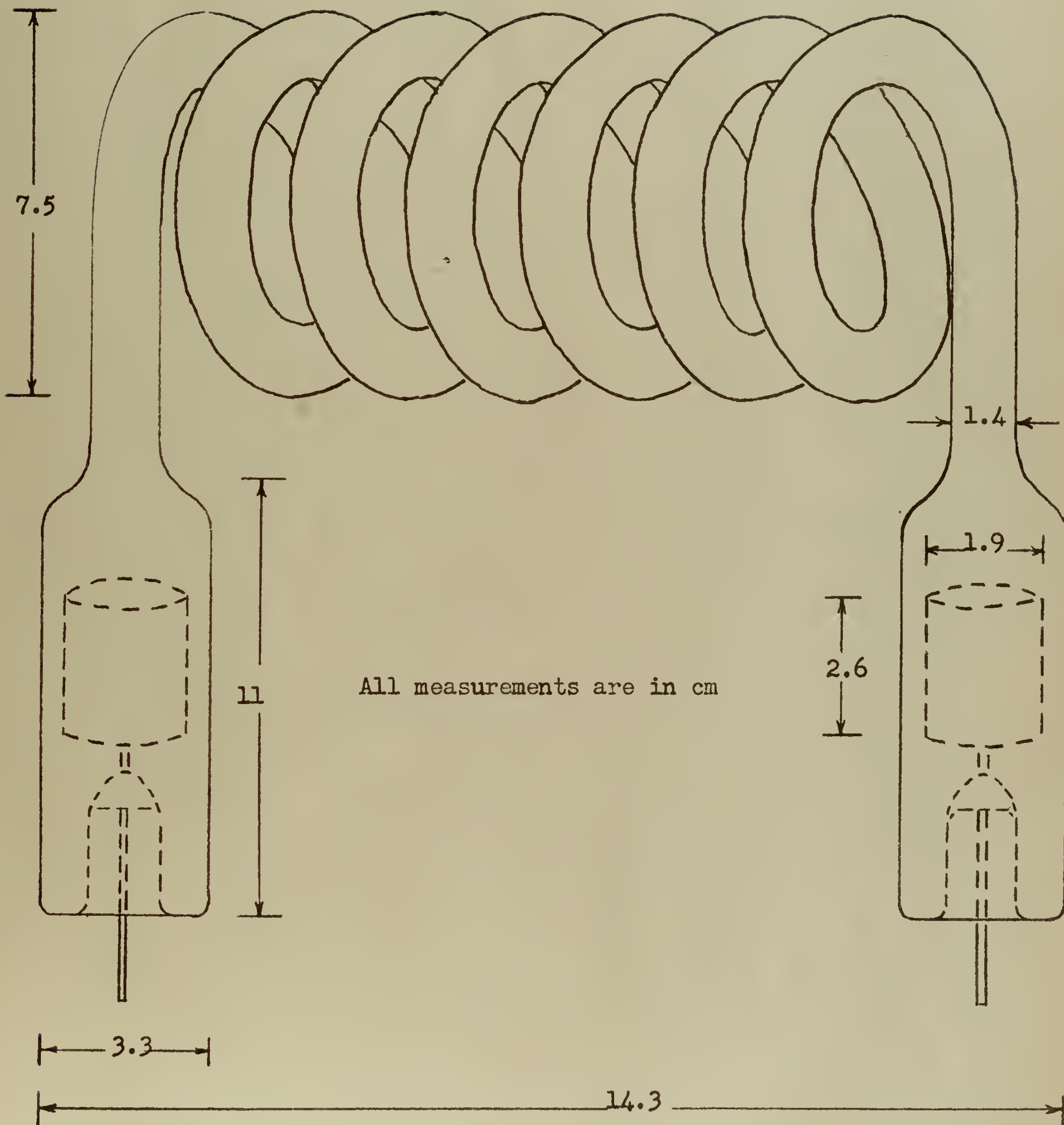


Fig. 5 - Details of Cataphoresis Tube

(b) Titanium metal (19) has been studied as a getter for O_2, N_2, CO_2, air, water vapor, H_2, and methane. Above 700°C titanium will getter O_2, N_2, and CO_2. Hydrogen is absorbed by Ti in the temperature range of 25 to 400° C. H_2 is the only gas which can be released by heating Ti after it has once absorbed hydrogen, therefore it may be useful to have two Ti getters for operation at high and low temperatures.

(c) Ti may also be used as an evaporative getter (27). Modifying the technique cited in reference (27), a series of Ti filaments may be heated, the evaporating Ti depositing on the walls of its pyrex envelope. Stable compounds are formed with the impinging gas molecules. For the rare gases, an electric field must be provided to attract the ionized gases to the walls where they are buried by the Ti. A commercial version of this, The Evapor-Ion pump, when used in a sealed off system eliminates contamination from diffusion pump vehicles. Pumping speeds of 7500 liters per second for N_2 and 1500 l/s for air, which contained 1% argon, have been attained.

7. Measuring techniques

Time and space variations in the light intensity of the striae within a gaseous discharge may be investigated by means of a photomultiplier tube and an oscilloscope. A traveling optical system is used to pick up light from the desired axial position along the discharge. A IP-21 photomultiplier tube will provide an amplification of 1×10^6 with optimum signal to noise ratio. Voltage, light intensity, and prove current may be displayed on the oscillograph at the same time and photographs of these traces may be taken. The probe circuit

may be arranged so that it is floating or at some potential with respect to the reference electrode. See figure 6 for the general component and circuit arrangement.

Photographing the reflections of the striations from a stainless steel mirror rotating about an axis parallel to the axis of the discharge tube provides a means for determining striation frequency and velocity. The mirror is driven by a variable speed transmission with a range from 0 to over 9000 rpm. The mirror is highly polished and optically flat.

An electronic counter is used to measure the tube voltage oscillation frequency. The counter will give readings as often as 0.1 sec. with an accuracy of $\pm$ 1 count.

8. List of equipment

Veeco vacuum gauge type RG-31A

Hewlett-Packard electronic counter model 521A

General Electric regulated d.c. power supply type YPD-4

RCA IP-21 photo-tube

Veeco ion tube type RG-75P

Hewlett-Packard vacuum tube voltmeter model 410B

Weston milliammeter model 322

Veeco thermocouple gauge

Veeco thermocouple gauge console

Jewell Electrical Instrument Co. a.c. ammeters

Topcon R prismatic reflex camera

Graham variable speed transmission model 30M55

Stainless steel mirror (locally built)

Kepco Labs regulated d.c. power supply mosel 1250B

Photo-tube power supply (locally built)

Tektronix dual beam oscilloscope type 551

Consolidated Vacuum Co. 3 stage water cooled diffusion pump

Weston d.c. voltmeter model 622

Weston d.c. ammeter model 622

Dumont oscillograph record camera type 299

Scientific Electric Co. induction heater model AC-5-LB

Burgess super heavy duty "B" batteries

Camera shutter (locally built)

Oven (locally built)

Partlow Instrument Co. thermostat model M2-10KL

Optical carriage (locally built)

W. M. Welch Mfg. Co. duo-seal vacuum pump

9. Preliminary Observations and Discussion

The effect immediately noticeable was that of the external circuitry on the discharge. The capacitance to ground effect was checked by varying it intentionally. It was found that voltage frequency decreased as the capacitance was increased. (A plot of this is shown in figure 9.) Other circuitry effects are still under investigation and it appears that great care must be taken in interpretation of results to avoid errors from this cause.

With the tube at a pressure of 5.11 mm Hg of Argon, a voltage-current characteristic was taken and the results are plotted in figure 10. It should be noted here that the modes that were stable on one day were not always stable on the next; therefore, these and subsequent plots may or may not be valid. After operating for a few days at this pressure, no stable modes were found to exist even after the interelectrode distance was

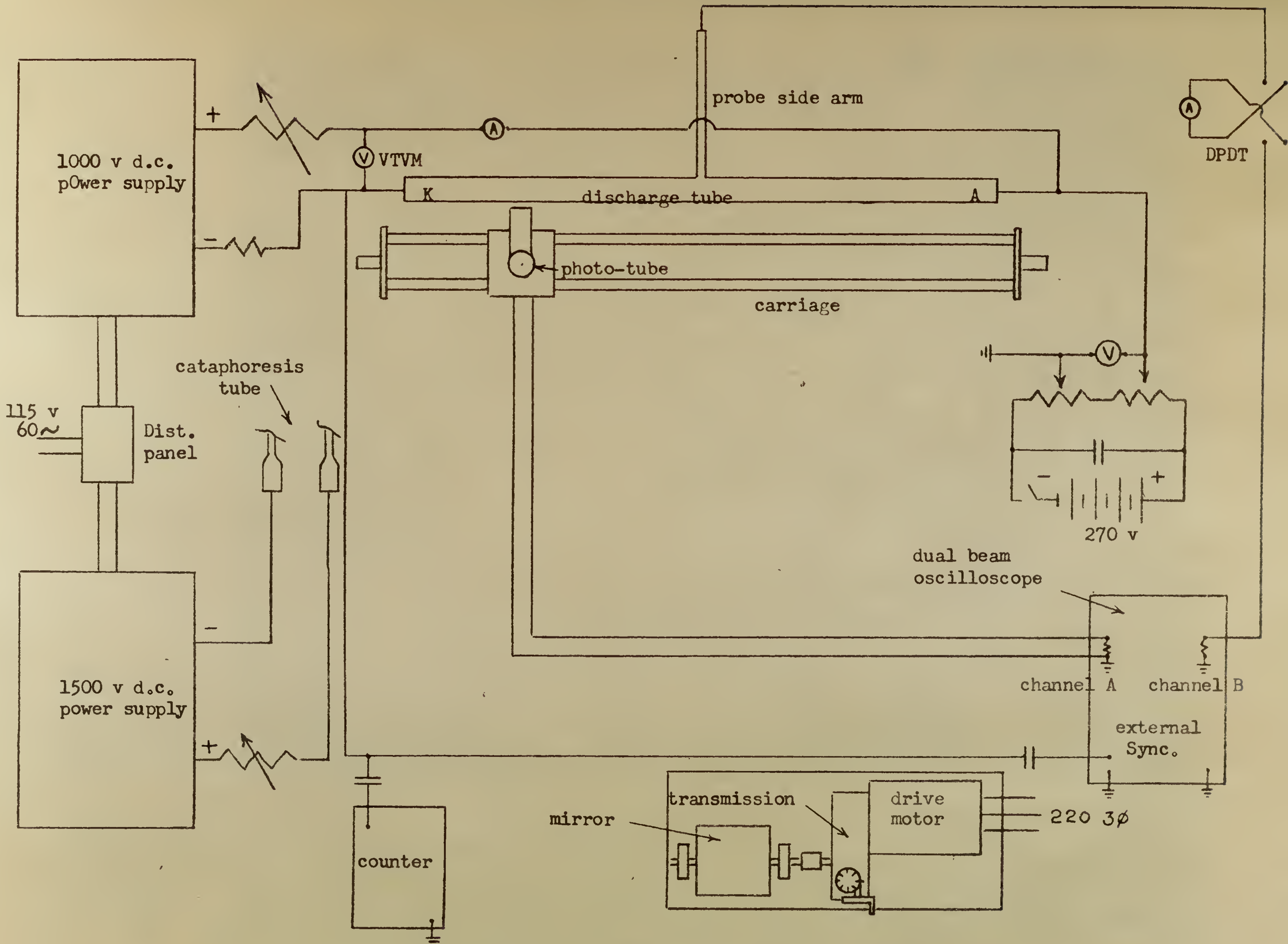


Fig. - 6 Schematic Diagram of Apparatus

[illegible] of Experimental Apparatus

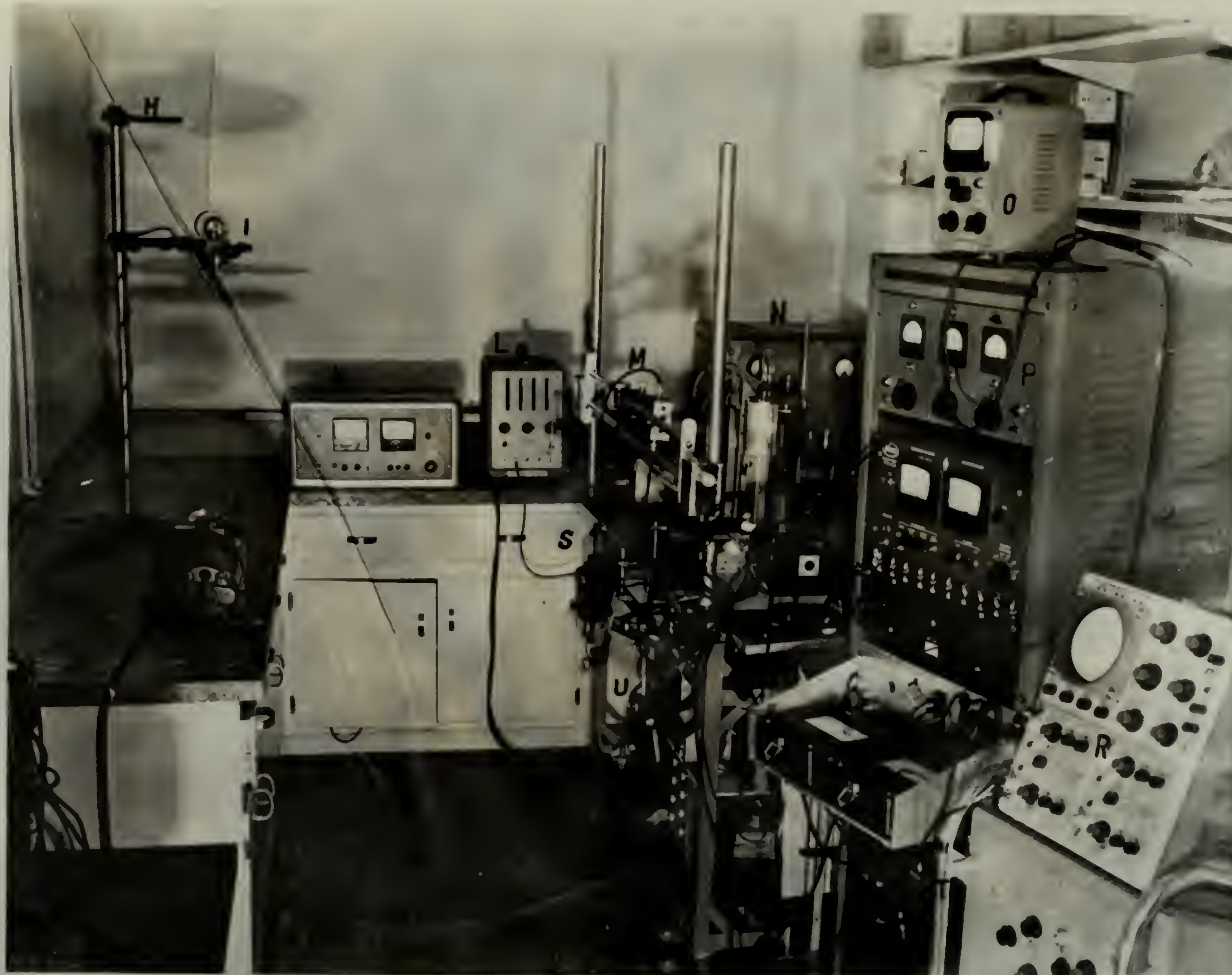


Fig. 7

H - Camera Support
I - Camera Shutter
J - Rotating Mirror
K - Ion Gauge
L - Electronic Counter
M - Photo-tube and Carriage
N - 1500 v d.c. Power Supply

O - VTVM
P - Photo-tube Power Supply
Q - Resistor Bank
R - Dual Beam Oscilloscope
S - Thermostat
T - 1000 v d.c. Power Supply
U - Fore Pump

Fig. 8

A - Cataphoresis Tube
B - Manifold
C - Ion Tube
D - Liquid-air Trap

E - Alpert Valve
F - Discharge Tube
G - Probe Side Arm

Photograph of Discharge and Cataphoresis Tube

varied.

The tube was then pumped out and refilled to a pressure of 10.3 mm Hg. In this region, the discharge had a definite tendency to stabilize at high voltage oscillations ($\sim$200 v) at around 40 to 60 ma with a frequency of about 500 cps. After approximately eight hours continued operation, a very stable mode appeared at a current of 54 ma and a frequency of 1440 cps. While in this mode, photographs were taken of the oscillograph at 0.5 cm intervals of the photo-cell. position along the tube. Part of this series of photos is shown in figure 11. A plot of distance from cathode vs. light intensity and striation position vs. time of peak light intensity is shown in figures 12 and 13 respectively. From the slopes of the lines in figure 13, the velocity of the striation in this mode was found to be 4730 cm/sec. This mode then became unstable and we were not able to obtain a rotating mirror photograph.

It appears that the attainment of some stable modes depends upon whether or not they are approached from a higher or lower current.

The positive column exhibited three distinct appearances. The first was homogeneous, the second had the appearance of a string of beads, and the third had a curious oblong shape resembling a "sausage", the latter of which was totally unexpected. (The three types did not necessarily appear in the above order.)

A considerable time lag occurs between the initial striking of the discharge and the appearance of stable modes of oscillation. It appears that stability is not attained for a period of several hours and may decrease after a further period. It is

possible that these effects may be due to evolutions of impurities from the hot electrodes and walls.

10. Recommendations for future work are as follows:

(a) Install a non-contamination type of pressure gauge in place of the manometer in order that a lower ultimate pressure may be obtained.

(b) Investigate the spatial distribution of electron temperature, ion density, and space potentials of the "sausage" type of discharge using probe techniques.

(c) Observe effects on the discharge of a variable inductance in series with the tube.

(d) Install one or more of the gettering devices described previously.

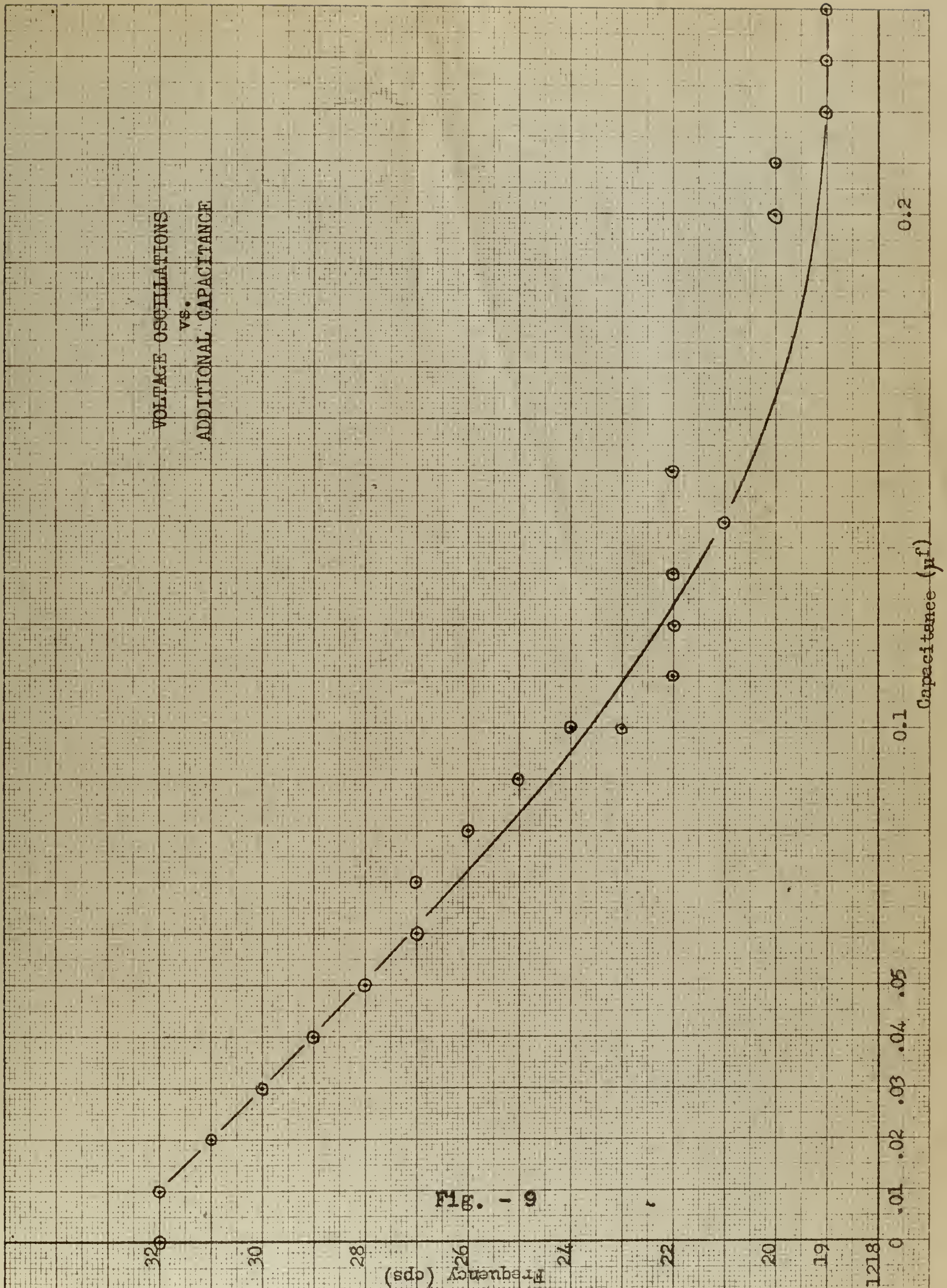
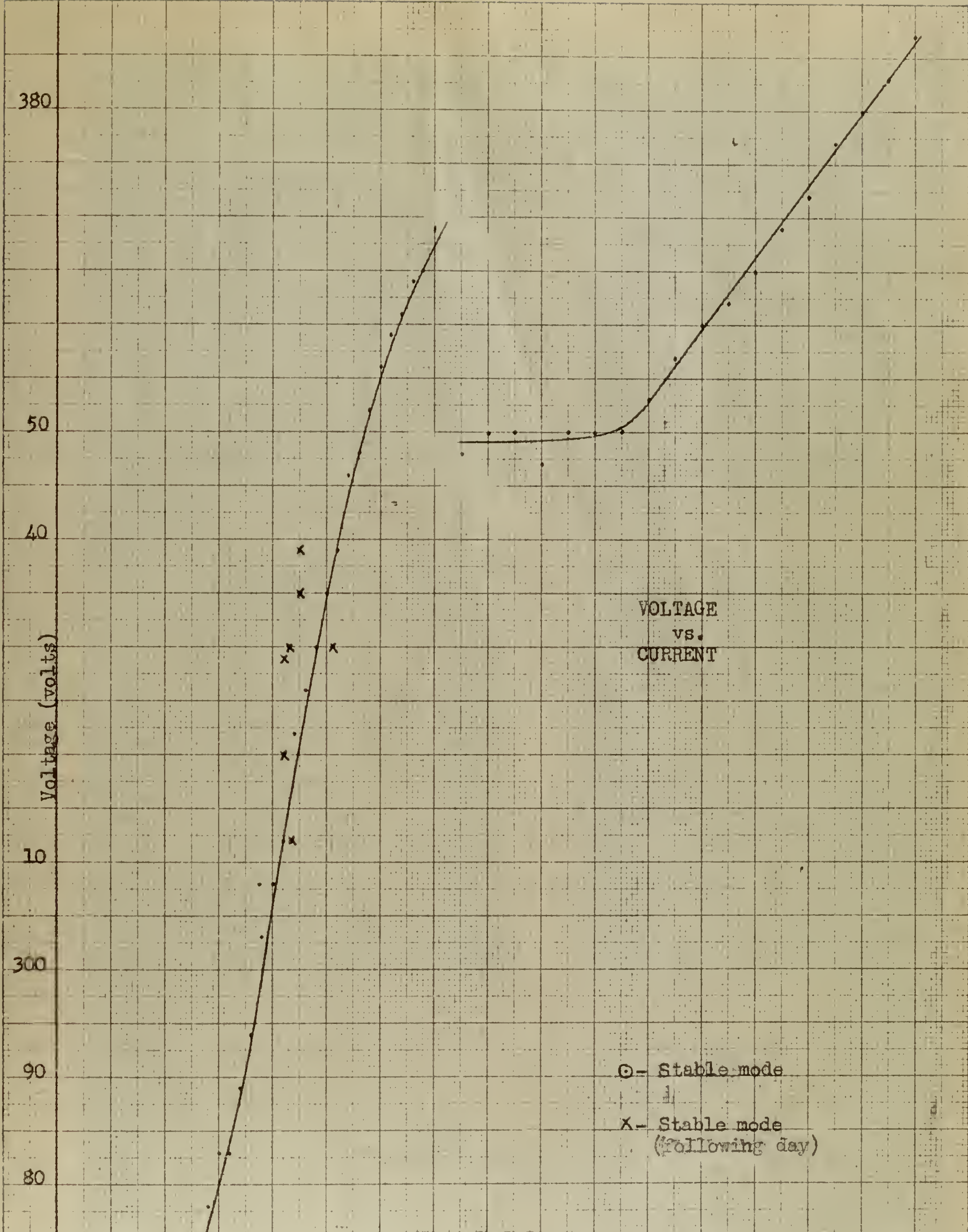
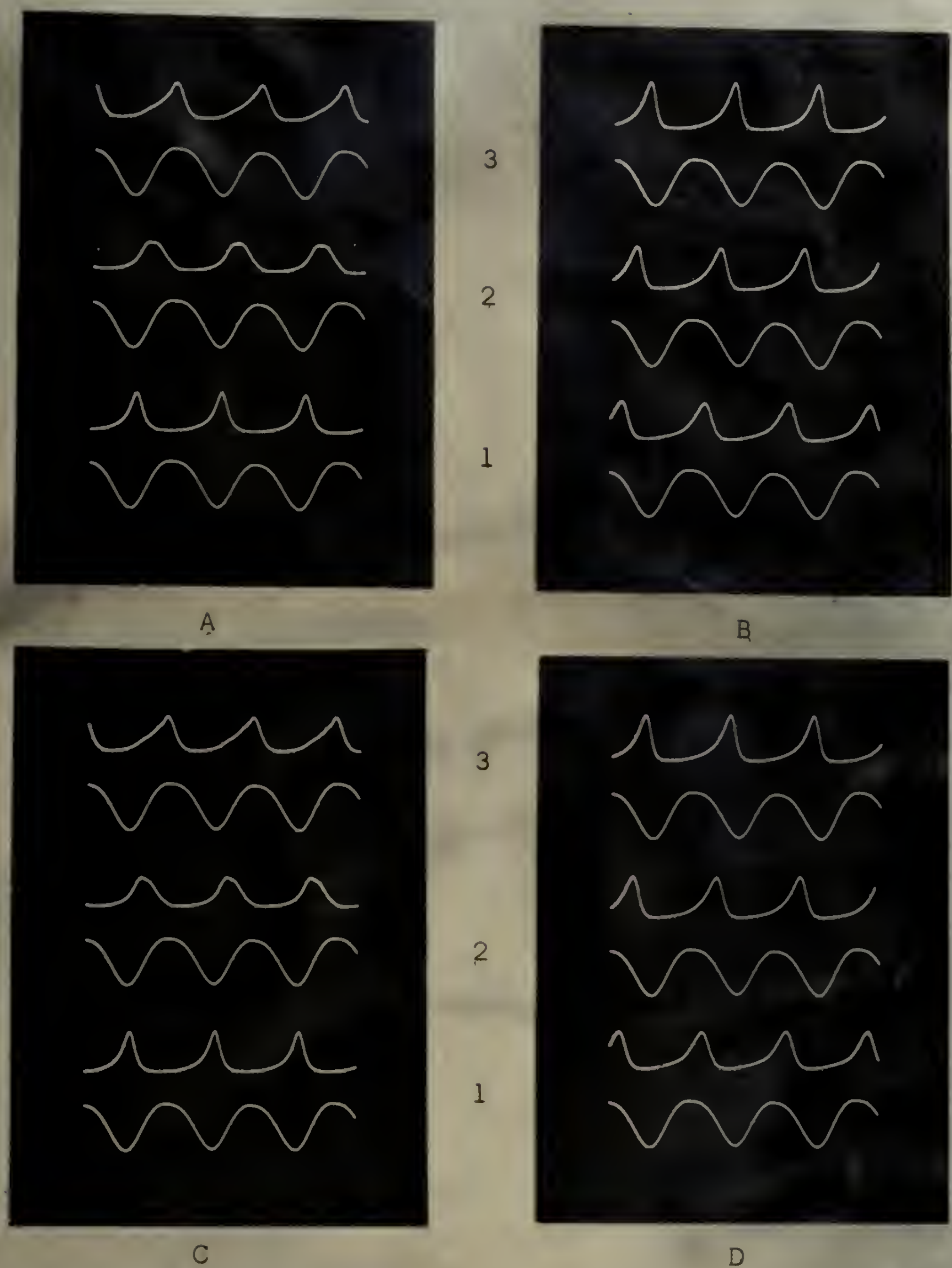

VOLTAGE OSCILLATIONS
vs.
ADDITIONAL CAPACITANCE
Frequency (cps)
Capacitance (μf)
32
30
28
26
24
22
20
19
0
.01
.02
.03
.04
.05
0.1
0.2

Fig. - 9



380
50
40
10
300
90
80
270
0
20
40
60
80
100
20
40
60
Voltage (volts)
Current (ma)
VOLTAGE
vs.
CURRENT
⊙- Stable mode
X- Stable mode
(following day)

Fig. - 10



Photographs of oscilloscope traces of light intensity and voltage oscillations

Frequency - 1443 cps
Current - 54 ma
Upper Trace - light intensity (0.2v/cm)
Lower Trace - voltage across tube (5v/cm)
Sweep - o.2 ms/cm

Distance from cathode (cm)

A1 - 11.3	C1 - 14.3
2 - 11.8	2 - 14.8
3 - 12.3	3 - 15.3
B1 - 12.8	D1 - 15.8
2 - 13.3	2 - 16.3
3 - 13.8	3 - 16.8

Fig. - 11

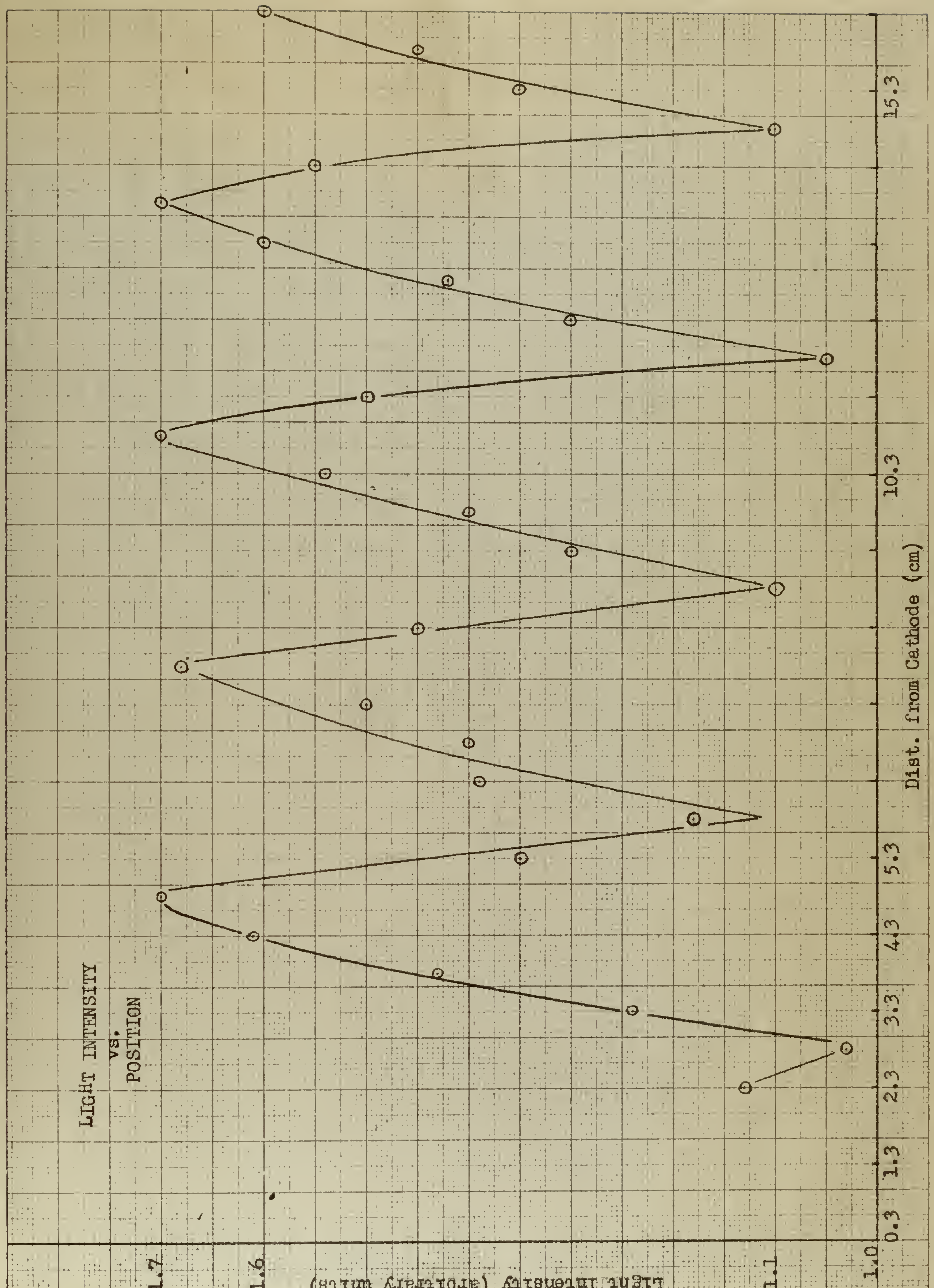

LIGHT INTENSITY
vs.
POSITION
Dist. from Cathode (cm)
0.3
1.3
2.3
3.3
4.3
5.3
10.3
15.3
Light Intensity (arbitrary units)
1.0
1.1
1.6
1.7

Fig. - 12

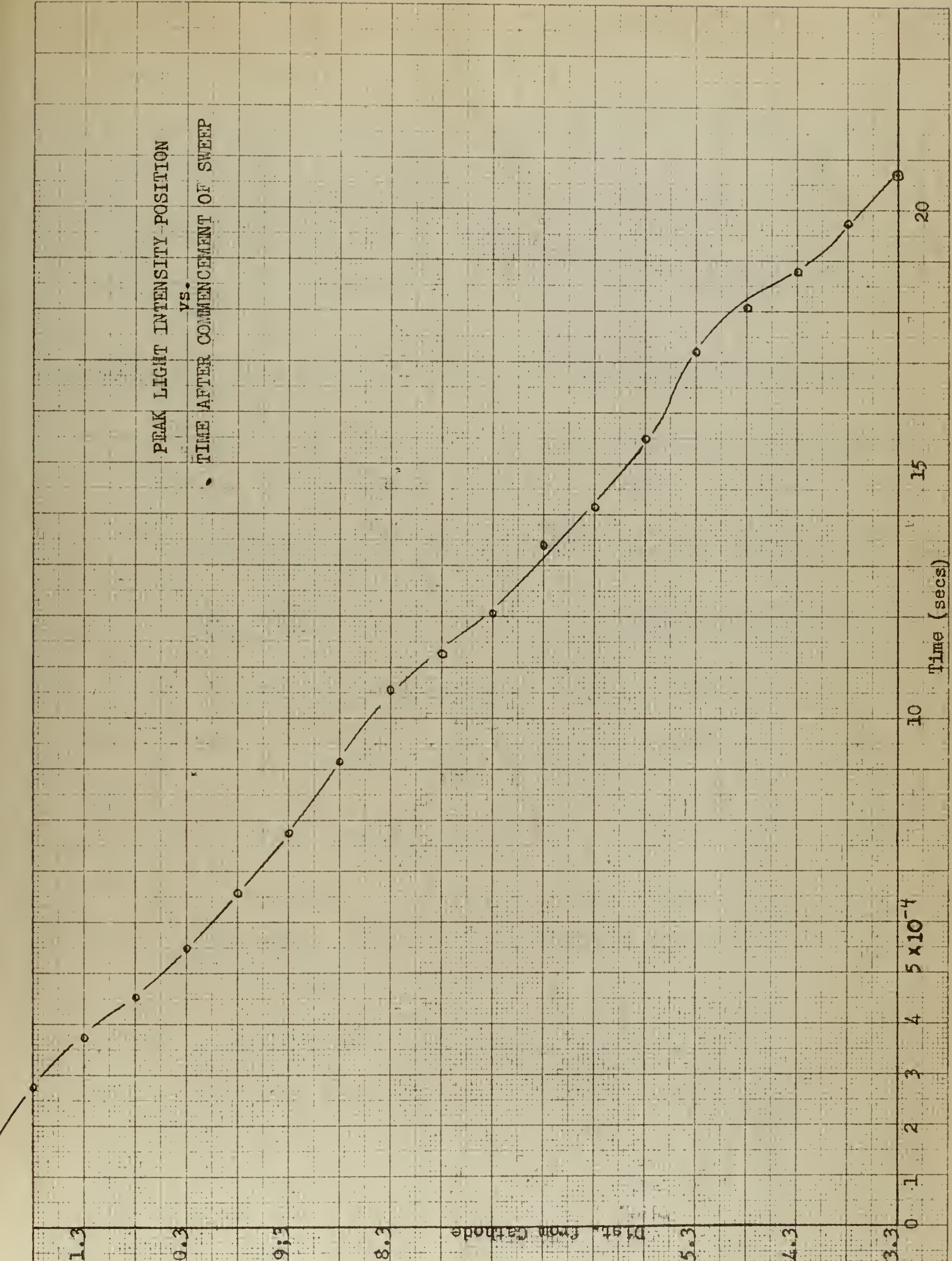

PEAK LIGHT INTENSITY POSITION
vs.
TIME AFTER COMMENCEMENT OF SWEEP
Time (secs)
5 x 10^{-4}
Dist. from Cathode
0 1 2 3 4 5 10 15 20
11.3 10.3 9.3 8.3 5.3 4.3 3.3

Fig. - 13

11. BIBLIOGRAPHY

1. A. A. Zaitsev and V. E. Mitsuk, Formation of Plasma Structure in a Developing Discharge, Doklady (U.S.S.R.), 311 (1958).

2. N. L. Oleson and A. W. Cooper, Moving Striations, Phys. Rev. 105, 1411-1412 (1957).

3. I. M. Chapnik, The Mechanics of Formation of Striations in the Positive Column of a Gas Discharge, JETP (U.S.S.R.) 34, 1496-1503 (1958).

4. L. B. Loeb, Mechanism of Cataphoretic Segregation in Inert Gas Glow Discharges, Journal of Applied Physics 29, 1369-1371 (1958).

5. W. Pupp, About the Influence of the Anode Upon the Stability of the Homogeneous Plasma Column in Argon, Physikalische zeitschrift 34, 756-761 (1933).

6. R. Riesz and C. H. Dieke, The Analysis and Purification of Rare Gases by Means of Electric Discharges, Journal of Applied Physics 25, 196-201 (1954).

7. S. Watanabe and N. L. Oleson, Traveling Density Waves in Positive Columns, Phys. Rev. 99, 1701-1704 (1955).

8. M. J. Druyvesteyn, Experiment on the Theory of the Positive Column with Moving Striations

9. D. Alpert, Production and Measurement of Ultra-High Vacuum, Journal of Applied Physics 24, (1953).

10. T. M. Donahue and G. H. Dieke, Oscillatory Phenomena in Direct Current Glow Discharges Phys. Rev. 81, 248-261 (1951).

11. R. L. F. Boyd and N. D. Twiddy, Electron Energy Distributions in Plasmas. 1, Proc. Roy. Soc. A 250, 53-68 (1959).

12. W. Pupp, Oscillographic Probing Measurements on Running Layers of the Positive Column of rare gases, Physikalische zeitschrift 36, 61-66 (1935).

13. A. B. Stewart, Oscillating Glow Discharge Plasma, Journal of Applied Physics 27, 911-916 (1956).

14. L. Tonks and I. Langmuir, Phys. Rev. 33, 195 (1929).

15. R. Whiddington, Nature 116, 506 (1925); 126, 470 (1930).

16. F. W. Aston and T. Kikuchi, Proc. Roy. Soc. A. 98, 50 (1921).

17. Takamine, Suga, and Yanagihara, Scientific papers, Inst. Phys. and Chem. Res. Tokyo 20, 63 (1933).

18. D. Alpert and R. S. Buritz, Limiting Factors on the Attainment of very Low Pressures, J.A.P. 25, 202-209.

19. V. L. Stout and M. D. Gibbons, Gettering of Gas by Titanium, J.A.P. 26, 1488.

20. N. L. Oleson and C. G. Found, Running Striations and Multiple electron Temperatures, J.A.P. 20, 416 (1949).

21. L. B. Loeb, Basic Processes of Gaseous Electronics (University of California press Berkeley and Los Angeles 1955), Ch. IV.

22. A. von Engel, Ionized Gases (The Clarendon Press, Oxford 1955).

23. J. D. Cobine, Gaseous Conductors (McGraw-Hill Book Co., New York and London 1941).

24. T. M. Donahue and G. H. Dieke, The Moving Striations in Argon Glow Discharges, N6 ONR 243, Task Order lV, Tech. Rpt. No. 3, 1949.

25. P. J. Walsh, Theory of Moving Striations, Westinghouse Research Rpt. BL-P-8-2097-3C3-19.

26. V. D. Farris, Investigation of Large Amplitude Oscillations and Turbulence in Gaseous Conductors, Thesis (Unpublished) 1954.

27. R. M. Hill, Ultra-High Vacuum and Gas Purification Techniques, Trip Rpt., pp 1-3 (1954).

28. O. B. Karge, B. W. Hooks, and N. L. Oleson, Moving Striations in an Argon Glow Discharge, ONR Tech. Rpt. No. 1.

29. M. E. Gerzenstein and V. V. Potemkin, Low Frequency Oscillations in the Positive Column of the Glow Discharge, JETP (U.S.S.R.) 24, (1953).

thesF39
Investigation of moving striations in an
3 2768 002 00139 8
DUDLEY KNOX LIBRARY